Recent news and results in the computation of NLO processes with new techniques*

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Abstract

I illustrate new techniques and recently obtained results in the computation of perturbative QCD processes at the NLO accuracy.

1 Introduction

The field radiative corrections for multi-particle processes has received a lot of attention, in the last few years, also thanks to new computational techniques [1, 2, 3] and to new tools [4, 5, 6, 7] that are nowadays available. Next to Leading Order (NLO) QCD calculations for Hadron Colliders physics are needed for two reasons. Firstly, they are an important ingredient for reliably computing backgrounds in new physics searches, that very often rely on analyses performed in rather narrow corners of the Phase-Space or in tails of distributions, where, on the one hand, not enough statistics is present to extract the background directly from the data and where, on the other hand, radiative corrections are expected to be large. Secondly, NLO calculations should be always preferred when measuring and constraining fundamental quantities of the Standard Model (SM), such as the mass of the Higgs particle (if found) and its couplings, M_W, α_S or $M_{\rm top}$. Both in the case of new physics searches, where the new produced particles undergo long decay chains, and in the case of SM measurements, where the hard event is accompanied by a rather strong jet activity, multi-leg final states are expected as a typical signature.

In this contribution, I review the main results that have been recently obtained in the subject of NLO QCD calculation for multi-leg final states observables.

2 NLO processes needed at the LHC

In Les Houches 2007, theoreticians and experimentalists agreed upon a list of processes interesting to know at the NLO accuracy in QCD [8]. In occasion of the following NLO multi-leg Les Houches workshop [9], the job was already almost accomplished, at least at the parton level, mainly due to new breakthrough techniques to compute the one-loop part of the NLO corrections [1, 2, 3].

For reader's reference I present, in table 1, the original list and the few entries added in 2009. At present, all the parton level processes in table 1, except $pp \to 4j$, are known at the

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$pp \to W + j$	$pp \to t\bar{t} + 2j$	$pp \to V + 3j$
$pp \to H + 2j$	$pp \to VVb\bar{b}$	$pp \to t\bar{t}b\bar{b}$
$pp \to VVV$	$pp \to VV + 2j$	$pp \to b\bar{b}b\bar{b}$
$pp \to t\bar{t}t\bar{t}$	$pp \to 4j$	$pp \to W + 4j$
$pp \to Z + 3j$	$pp \to Wb\bar{b}j$	

Table 1: The original 2007 Les Houches Wish List (top) and its 2009 update (bottom).

the NLO accuracy in QCD, in the sense that theory papers have been written containing NLO results and distributions. However, it has to be pointed out that, even if table 1 looks quite impressive, the final NLO product, needed from an experimental point of view, should be a usable code, fully automatic and matched with Parton Shower and Hadronization.

Progress in the direction of a complete full automation of parton level NLO predictions has been achieved very recently by the authors of the MadLoop code of [7], where the ability of MadGraph [10] to compute amplitudes is merged with the OPP integrand reduction method implemented in CutTools to automatically generate one-loop corrections. On the other hand, interfacing with the Parton Shower and Hadronization is possible within the MC@NLO [11] and POWHEG [12] frameworks.

Finally, the first attempt of automatizing *both* the NLO computations *and* the subsequent merging with the Parton Shower and Hadronization codes is under way, under the name aMC@NLO [13, 14].

3 NLO Tools

It is evident that sophisticated programs are needed to compute multi-leg processes at NLO. The existing tools can be naturally divided in three categories, as listed in table 2, namely codes based on Analytic Formulae, on traditional Feynman Diagram techniques and, finally, on OPP or Generalized Unitarity methods. As usual, most of the programs have been cross checked, to establish their technical agreement. An example of such *tuned* comparisons is reported in table 3, for the process $pp \to ttbb$. It is a remarkable fact that the two codes use two completely different techniques. Analogous successful comparisons have been performed by the Golem group and the team Dittmaier, Kallweit and Uwer on $pp \to ZZ + j + X$ [9].

The second, even more important task of the comparisons, is the assessment of the theoretical accuracy at which a given process is known. In this second type of exercise, each program freely varies a few parameters (such as renormalization and factorization scales). The goodness of the LO prediction (at least in the shape of the distributions) can also be determined that way. In fig. 1 I report, as an example, the result of a comparison of BlackHat, Rocket and Sherpa on $pp \to W + 3jets$ at NLO.

As it can be easily understood, with the advent of the LHC data the techniques used to obtain the NLO results are getting less and less important, since the interest is now going towards commonly accepted interfaces to merge different parts of the NLO calculations. As an example, an accord to interface Monte Carlo (MC) programs, generating the real radiation, together with programs providing the virtual one-loop contributions (OLP), can be found in [21] (the so called Binoth Les-Houches accord). In fig. 2, I show this accord at work between BlackHat/Rocket on the OLP side and MadFKS [22] on the MC side, in the case of

Analytic Formulae:
MCFM [15]
Feynman Diagrams:
Bredenstein, Denner, Dittmaier, Pozzorini [16] FormCalc/LoopTools/FeynCalc [17] Golem [18]
OPP/Generalized Unitarity:
MadLoop [7] Helac-NLO/Cuttools [4, 6] BlackHat/Sherpa [3] Rocket [5] Golem/Samurai [19, 20]

Table 2: Some available NLO tools.

Process	σ^{LO} [fb] [16]	σ^{LO} [fb] [6]	σ^{NLO} [fb] [16]	σ^{NLO} [fb] [6]
$q\bar{q} \to t\bar{t}b\bar{b}$	85.522(26)	85.489(46)	87.698(56)	87.545(91)
$pp \to t\bar{t}b\bar{b}$	1488.8(1.2)	1489.2(0.9)	2638(6)	2642(3)

Table 3: Example of *tuned* comparisons between HELAC-NLO [6] and the program of [16].

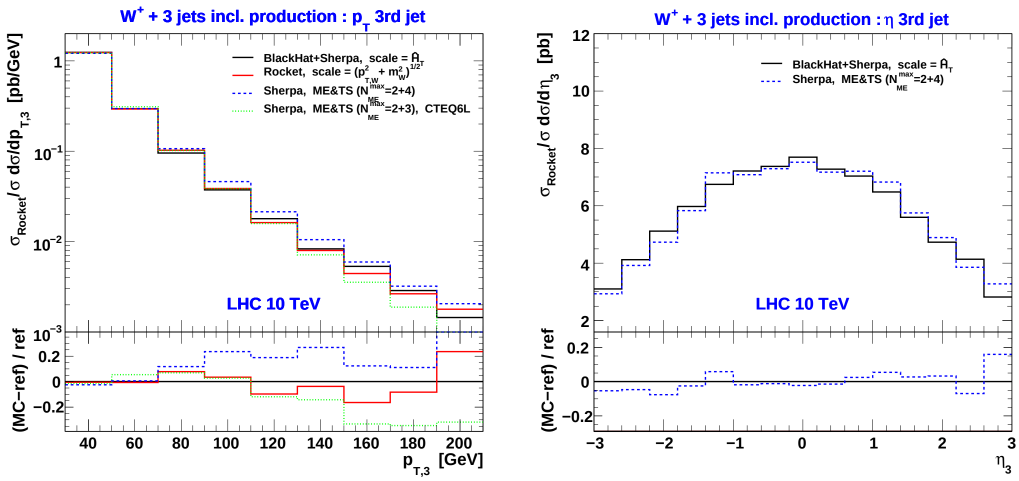

Figure 1: Comparisons on $pp \to W + 3jets$: p_t and rapidity of the 3rd jet.

$e^+e^- \to jets$ as implemented by Frederix, Maitre and Zanderighi [9]. The Binoth Les-Houches accord is also used by aMC@NLO [13, 14] to interface virtual and real corrections.

Finally, it should be noticed that the field is evolving so rapidly that new NLO processes are continuously computed. As an illustrative example, I quote $pp \to W^+W^\pm jj$ in [23, 24], $pp \to t\bar{t} \to W^+W^-b\bar{b}$ including all off-shell effects in [25, 26] and $pp \to Wjjjj$ [27].

4 Conclusions

I have presented recent progresses in our theoretical understanding of perturbative QCD at NLO. New automatic NLO tools exist nowadays to deal with the LHC data and to cope with the complexity of the present and forthcoming measurements. The further step of automatically interfacing such programs with Parton Shower and Hadronization has already been undertaken.

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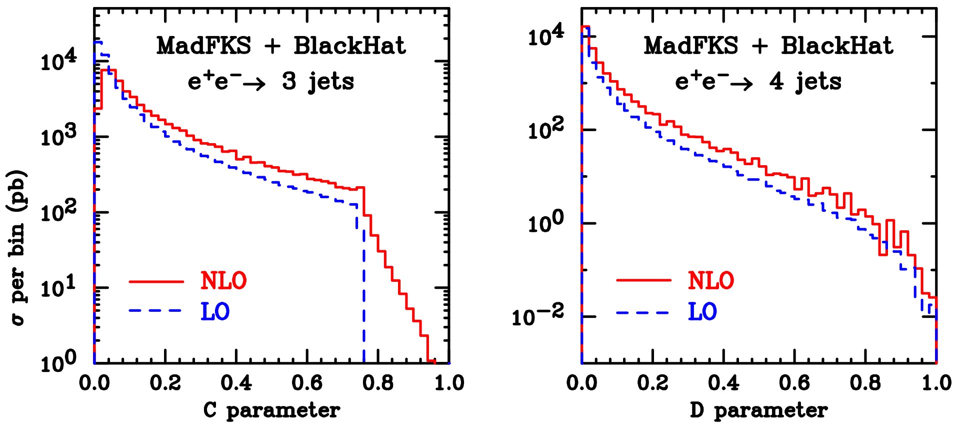

Figure 2: Results on $e^+e^- \to jets$ using the Binoth Les Houches accord.

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